NORTH COAST AND CASCADES NETWORK
GLACIER Protocol Summary Format

Title: Glacial mass balance, contribution to streamflow and hazards

Parks: Mount Rainier, Olympic, North Cascades

Justification: Glaciers are a significant resource of many mountain ranges of the world, including the three large parks in the NCCN. Combined, the glacial resources of this network are extensive, covering 235 km^2. They are integral components of the region's hydrologic, ecologic, and geologic systems, and they are retreating rapidly. At NOCA, geologic mapping data and a 1998 inventory (Granshaw, 2001) indicate that glacier area has declined 44% in the last 150 years. Glaciers were rated by NCCN as the fourth priority for monitoring, and were listed as important Vital Signs for OLYM, NOCA and MORA.

Glaciers effect the distribution of aquatic and terrestrial habitat through their advance and retreat. Many of the subalpine and alpine plant communities in the NCCN flourish on landforms and soils created by glaciers within the last century. Glaciers directly influence aquatic habitat by the amount of cold, turbid melt water and fine-grained sediment they release. Glaciers also indirectly influence habitat through their effect on nutrient cycling and microclimate.

The influence of glaciers on NOCA and regional hydrology is immense in both the quantity and timing of discharge of glacial melt water. Post and others (1971) estimate that glaciers contribute 800 million cubic meters to streamflow annually in the North Cascades alone. In the Thunder Creek watershed (250 km^2 area) glaciers contribute as much as 45% of the total summer runoff (NOCA unpublished data) during the hot, dry summers in the Pacific Northwest, buffering the region's aquatic ecosystems from seasonal and interannual droughts. Aquatic ecosystems, endangered species such as salmon, bull trout and western cutthroat trout, and the hydroelectric and agricultural industries benefit from the stability glaciers impart to the region's hydrologic systems.

The sensitive and dynamic response of glaciers to variations in both temperature and precipitation makes them excellent indicators of regional and global climate change at multiple time scales. This feature of glaciers is particularly valuable at remote high elevation sites in the NCCN, where meteorological data are not available. Glaciers also provide valuable insight to climate change over longer time periods than most other climate measures (Paterson, 1981).

Monitoring Objectives:
Four broad goals are identified to monitor glaciers as important Vital Signs of the ecological health of NCCN, following the guidance of Davis (1993) and Silsbee and Peterson (1991):

1) Monitor range of variation and trends in volume of NOCA glaciers;

2) Relate glacier changes to status of aquatic and terrestrial ecosystems and hazards;
3) Link glacier observations to research on climate and ecosystem change;
4) Share information on glaciers with the public and professionals

To meet the primary goal of monitoring the range of variation and trends in the volume of several hundred glaciers covering >300 km^2, monitoring must occur at multiple spatial and temporal scales, and at variable levels of intensity. Objectives identified to reach this goal include:

- Identify index glaciers to represent larger population of NOCA, OLYM and MORA glaciers;
- Seasonally monitor the mass balance of index glaciers;
- Measure the geometry of index glaciers every 10 years;
- Monitor variation of the area and volume of the entire population of glaciers with a comprehensive inventory at MORA every 5 years and at NOCA and OLYM every 20 years.

Based on the broader goals and related objectives identified above, there are seven measurable objectives for the monitoring described in this protocol:

- winter balance at index glaciers;
- summer balance at index glaciers;
- net mass balance at index glaciers;
- assess surface cover in late fall for each index glacier;
- assess surface features (lakes, crevasse patterns, debris cover) changes related to glacial hazards;
- glacier volume/area for index glaciers at 10-year intervals;
- glacier volume/area for all glaciers at 20 year intervals;
- glacial contribution to summer runoff for four watersheds at NOCA, two at MORA and one at OLYM.

Monitoring Approach:

The sample designs utilized in this project were developed in cooperation with USGS Water Resource Division, Portland State University, and the University of Washington. Sample design consists of a multi-scaled approach that incorporates different measurement frequencies for different indicators. Monitoring scales include individual glaciers, watersheds, and the entire population of NOCA glaciers. Sampling frequencies include seasonal, annual, decadal, and 20-year periods.

The primary indicator is detailed annual mass balance monitoring of a small sample of the glaciers at each park. This "index glacier" approach has been used in most glacier monitoring programs, due to cost and logistical problems associated with sampling an extensive population in rugged terrain. Mass balance also provides direct links to weather and streamflow. USGS used this approach in designing its Benchmark Glacier Program, and in the selection of South Cascade Glacier (Figure 1) to represent the larger population of glaciers in the North Cascades. Recent research has supported use of the

index glacier approach (Fountain, 2001). At NOCA four index glaciers are being monitored, while there are two index glaciers at MORA and one at OLYM.

Glacier area changes are the second indicator and provide a direct measure of the advance and retreat of all glaciers, and the concomitant creation and destruction of terrestrial and aquatic habitat. Area changes of all park glaciers are accomplished via repeated inventories. These inventories are based on IKONOS satellite or stereo aerial photographs, and will occur at varying frequencies depending on the park. At MORA, where glaciers contribute to hazards on an active volcano, glacier inventories area scheduled for every five years. At OLYM and NOCA these inventories are scheduled for 20 year intervals.

Glacier area changes are directly related to changes in volume and are used to monitor the third indicator – glacier meltwater discharge. Meltwater discharge provides a seasonal estimate of water accumulation, storage, and loss, as well as an estimate for extrapolation to the larger population of glaciers in the park. These measurements will be undertaken at three watersheds at NOCA, two watersheds at MORA and one at OLYM.

Principal Investigators: Jon Riedel (NOCA) and Paul Kennard (Region at MORA)

Status, Development Schedule, Budget, Deliverables:

(1) Status - Glacier monitoring at NOCA is entering its 13th year, while this is the third year glacier at MORA will be monitored. University of Washington monitors Blue Glacier at OLYM using a model that relies on input from the Quillayute weather balloon. A complete protocol for monitoring glaciers at NOCA is in final review draft, while the protocols for MORA and OLYM are in development. Current glacier monitoring at MORA is guided by a peer-reviewed study plan, and will form the basis for development of a protocol. A study plan for monitoring glaciers at OLYM is in initial stages of development. As at present, OLYM will rely upon existing University of Washington model for annual measurements of the mass balance of Blue Glacier.

(2)Schedule:

- Summer 2004: =continue to monitor NOCA and MORA index glaciers
  =complete draft MORA protocol
  =initiate development of OLYM protocol
- Winter 2004-2005: =finalize MORA protocol
- Summer 2005 – Winter 2006 = complete OLYM protocol
- Summer 2006 = implement all three protocols

(3) Budget notes:
Protocol development:

- NOCA protocol is 95% completed, cost was about $30,000. Developmental costs were incurred before the Natural Resource Challenge was funded.
- MORA protocol $45,000 total for development, protocol writing and peer review. For FY04 and 05 $30,000 total (spent $15,000 to date on development and peer review of NOCA protocol and MORA study plan). FY05 $10,000 from NCCN funds to pay for peer review, plus $5,000 from NOCA Prototype Park base.
- OLYM protocol $15,000 total for development, protocol writing and peer review. This will be spread over two FYs; with $5,000 in FY05 for development and $10,000 in FY 06 for peer review contract and protocol writing. OLYM is relatively low cost due to reliance upon existing University of Washington model for annual measurements, which is simpler than field work at NOCA and MORA. OLYM can use NOCA protocol for glacier inventory.

Annual glacier monitoring:
Budget for monitoring three glaciers at NOCA and two at MORA:

A. Fixed costs	$17,000 (Lead Tech. Salary $11,250 NOCA; $5,750 MORA)
B. NOCA costs	$ 7,600
C. MORA costs	$16,865 (includes Nisqually Survey)
Total	$41,465

Decadal index glacier mapping and 20-year glacier inventories are necessary to meet the goals and objectives. Approximate costs for remapping index glaciers every 10 years are $15,000/park or $30,000 total. The need to monitor changes in the population of all glaciers at all three parks in 20-year intervals is reflected in the protocols. It is estimated that each of these inventories will cost $40,000, not including the additional cost for the imagery the inventory is based on (air photos or satellite). Should NCCN funds not be able to support this effort, we will seek outside funds from the Combined Program call or other grants to pay for the inventory projects. Current inventories of glaciers are 7 years old at NOCA, 10 years at MORA, and 25 years at OLYM, making OLYM the top priority as soon as airphotos and funds are available.

(4) Deliverables 2004-2005

A) Digital

=updated GIS maps of NOCA and MORA index glaciers
=winter accumulation, summer melt, and net mass balance data for ~30 sites on 6 index glaciers
=metadata files updated annually
=estimates of glacial contribution to streamflow for five valleys (3 NOCA, 2 MORA)

B) Documents

=final NOCA glacier monitoring protocol
=first draft MORA glacier monitoring protocol
=10 year NOCA data summary

=annual glacier pages for regional streamflow forecast

C) Other

=annual vertical stereo air photos of 6 index glaciers

=field data forms

References

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